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U. S. DEPARTMENT OF AGRICULTURE,

WEATHER BUREAU.

RECENT PRACTICE IN THE ERECTION OF LIGHTNING CONDUCTORS.

Prepared under the direction of WILLIS L. MOORE, Chief U. S. Weather Bureau.

BY

ALFRED J. HENRY,
PROFESSOR OF METEOROLOGY.

WASHINGTON:
WEATHER BUREAU.
1906.

LETTER OF TRANSMITTAL.

U. S. Department of Agriculture,
Weather Bureau,
Washington, D. C., February 2, 1906.

Hon. James Wilson,
Secretary of Agriculture.

Sir: I have the honor to transmit herewith a report entitled Recent Practice in the Erection of Lightning Conductors, by Alfred J. Henry, Professor of Meteorology, and to recommend its publication as a bulletin of the Weather Bureau.

Very respectfully,

Willis L. Moore,
Chief U. S. Weather Bureau.

Approved.

James Wilson, *Secretary.*

TABLE OF CONTENTS.

RECENT PRACTICE IN THE ERECTION OF LIGHTNING CONDUCTORS.

By Alfred J. Henry, Professor of Meteorology.

It can not be said that there is any uniformity of practice in the erection of lightning conductors in the United States. In large cities one occasionally sees a residence on which they have been installed, more often a church, but very rarely a public building. The Federal Government does not install lightning conductors on any of the buildings it erects. In the case of powder magazines, however, the Ordinance Department of the Army provides a very complete system of protection from lightning. So too in the case of overhead electric power circuits that enter Federal buildings care is taken to protect the building from flashes that may come over the line. That the Government engineers are not without appreciation of the value of lightning conductors is evinced by the very complete system of protection installed upon the Washington Monument in 1885. In the application of lightning conductors to the monument the engineers in charge were guided by sound principles, and as might justly be expected, established a system of protection that has successfully performed its functions for more than 20 years. A detailed description is here reproduced since the original document is now inaccessible to the general public. (Senate Ex. Doc. No. 6, 49th Cong. 1st Session.)

LIGHTNING CONDUCTORS ON THE WASHINGTON MONUMENT.

The lightning conductors, as established for the monument, were commenced in January, 1880, and were finished in January, 1885. These conductors consist of 4 hollow wrought-iron Phoenix columns standing in the well of the shaft, and which support the elevator machinery and guide the car. These columns are 6 inches in exterior diameter, five-eights of an inch in thickness, and are made up of sections 20 feet in length fastened together with long inside couplings, which fit tightly into the columns, and are fastened to them by 16 screw bolts. The bottoms of these 4 columns rest upon and are bolted to cast-iron shoes, which in turn stand upon the floor of the large drum pit beneath the floor of the monument. The shoes are connected to three-quarter inch soft copper rods led to the bottom of a well in the center of the foundation. This well is 32 feet 10 inches in depth below the bottom of the drum pit, and 15 feet 8 inches below the bottom of the masonry foundation, and the water stands in it permanently 2 feet 8 inches above its bottom. After the copper rods were inserted the well was filled with clean sharp sand for a depth of 15 feet 8 inches, or up to the level of the bottom of the old rubble-stone foundation of the monument. These 4 columns so arranged at their bases, and always projecting above the top of the shaft, were continually lengthened as the building of the shaft progressed, and for the 5 summers during which the masonry was in progress acted as the lightning conductors of the

edifice. No disruptive discharge of electricity was experienced during those 5 years.

When the walls were completed, in December of 1884, and the upper extremities of the columns were covered in by the marble pyramidion, 4 copper rods, three-quarters of an inch in diameter, were run, one from each column, to the top stone, and there united in a $1\frac{1}{2}$ inch copper rod, which passing vertically through the stone, was screwed into a solid metal terminal of aluminum. This metal was selected for the terminal because of its whiteness, and the probabilty that its polished surfaces would not tarnish upon exposure to the air. It was a square pyramid in shape, similar to the pyramidion of the obelisk, and, fitting upon the top stone, completed the apex. This terminal weighed 100 ounces, and was 8.9+ inches in height and 5.6+ inches in width at the base. The angle at the vertex between 2 opposite sides was about $34° 48'$.

The conductors, as above described, when tested gave an electrical resistance of one-tenth of an ohm from the tip of the terminal to the copper rods at the base, and two and two-tenths ohms for the ground connections, making a total resistance of two and three-tenths ohms for the conductor. The system was entirely completed and connected on January 20, 1885.

On the 5th of April, 1885, during the passage of a heavy thunder cloud over the monument, at least 5 immense sparks or bolts of electrical light were seen within a period of 20 minutes to flash between the terminal and the cloud, without audible sound to the observers. A careful examination of the conductors and shaft after these phenomena failed to reveal any effects from these discharges.

On the 8th of June, however, during a thunderstorm, a disruptive discharge was seen to pass between the summit of the pyramidion and the cloud. Upon examining the structure a crack was discovered in the stone on the north face of the pyramidion just under the top stone, extending through the block in a line nearly parallel to the northeast corner, and about eight and one-half inches from it. The fragment was pressed outwards about three-quarters of an inch at its bottom, chipping a small piece off the lower corner of the top stone into which it was locked, and was easily forced back to place and bolted to the solid stone from which it had been torn.

Under the circumstances of this damage, and to devise if possible some plan by which the obelisk could be more effectually protected from lightning, Professors H. A. Rowland, of the Johns Hopkins University, Simon Newcomb, of the United States Navy, and T. C. Mendenhall, of the United States Signal Service, were invited to inspect the conductors and recommend any modifications in them, which in their judgment would be proper for the end required. This they kindly consented to do, and after a careful examination recommended, in substance, that the interior conductors should be connected with a system of rods and a greater number of points to be located upon the exterior of the pyramidion. The additions, as devised by them, consist of 4 one-half inch copper rods, fastened by a band to the aluminum terminal and led down the corners to the base of the pyramidion; thence passing through the masonry they extend inward and are joined to the iron columns above described. As these exterior rods are each over 60 feet long, they are also connected at two intermediate points of their lengths with the iron columns by means of copper rods one-half and three-quarters of an inch, respectively, furnishing sixteen rods in all connecting the exterior system of conductors with the interior conducting columns. Where the exterior rods upon the corners cross the eleven highest horizontal joints of the masonry of the pyramidion, they are connected to each other all around by other copper rods sunk into those joints. All of these exterior rods, couplings, and fittings are gold plated, and are studded at every 5 feet of their lengths with copper points 3 inches in length, gold plated and tipped with platinum. There are 200 of these points in all. * * *

LIGHTNING CONDUCTORS IN URBAN DISTRICTS.

In urban districts the application of lightning conductors to farm and residence buildings is much more common than in the larger towns and cities. Whether or not lightning conductors shall be installed on buildings is generally determined by the individual judgment of the owner. So far as known, the architects' plans, when such are used, do not provide for lightning conductors.

APPARENT DECREASE IN USE OF LIGHTNING CONDUCTORS.

It seems probable that there has been a decided falling off in the use of lightning conductors within the last 30 years. According to the United States Census statistics, there were, in 1860, twenty establishments manufacturing lightning rods, which turned out a product valued at $182,750. In 1870 the number of establishments had risen to 25 and the value of the products to $1,374,631. In the next decade the number of establishments fell to 20 and the value of the product to $801,192, and finally in 1890 the number of establishments rose to 22, but the value of the product diminished to $483,296. At the census of 1900 the classification in vogue from 1860 to 1890 was abandoned and lightning rods were tabulated in the general classification "Foundry and Machine Shop Products." There are no means of determining absolutely whether the large decrease in the value of the manufactured product from 1870 to 1890 marks a decline in the use of lightning conductors; certain it is, however, that the "Lightning Rod Man" is not so much in evidence as he was in the early seventies.

The possibilities and the limitations of a properly installed lightning rod are fully set forth on the pages which follow. In general the conclusions therein reached are in close accord with those of the Weather Bureau officials who have given attention to the subject. In large cities the use of lightning rods is not imperative owing to the prevalence of modern steel structures and in general buildings with metal roofs. For buildings that stand isolated in the open country the prudent course would be to install thereon a system of protection from lightning. The extent to which the building should be protected and naturally the expense of installation should bear some definite relation to the value of the building. If the building is insured against loss by fire or lightning, it would not seem advisable to go to the additional expense of erecting lightning rods. In any event the final decision must be reached by the owner of the building. In arriving at his decision he should be guided by the fact that, while absolute security from damage by lightning is attainable only with great difficulty and considerable expense, a reasonable degree of protection can be secured by very simple means, provided the system of protection be devised and erected by a thoroughly competent person.

REPORT OF LIGHTNING RESEARCH COMMITTEE. (GREAT BRITAIN.)

There recently appeared in the Journal of the Royal Institute of British Architects, Third Series, Volume XII, No. 13, a report made by the Lightning Research Committee, a committee that was formed for the purpose of obtaining trustworthy information on disasters suffered by buildings from lightning, of investigating causes of failure of lightning conductors to protect, and finally of suggesting, if possible, improved means of protection. A short preface to the report was written by Sir Oliver Lodge, F. R. S. Both the preface and the report of the committee contain so much information of value to American architects and builders that a very full abstract is here given. Acknowledgment is made of our indebtedness to the committee which formulated the report, as well as to the Journal of the Royal Institute of British Architects, which published it.

REPORT OF THE LIGHTNING RESEARCH COMMITTEE. (GREAT BRITAIN.)

PREFACE.

By Sir OLIVER LODGE, F. R. S.

Since the report, many years ago, of the Lightning Rod Conference knowledge of the subject has considerably increased and the effect of self-induction, which then was completely ignored, has been taken into account and understood. The main differences between what is recommended to-day and what was considered sufficient then depend on the recognition of the influence of self-induction or electrical inertia. Then electricity was treated as if it had no inertia, and as if all that was necessary was to get it from the clouds to the earth as quickly and easily as possible by the shortest path, which may be called the drain-pipe theory. It was supposed that it would always take the easiest path, and that the easiest path would protect all others. Attention was directed to the quantity of electricity which had to be conveyed down, and to nothing else.

Now, however, it is perceived that it is not so much quantity of electricity that has to be attended to as electrical energy; that this electrical energy is stored between clouds and earth in dangerous amount, and that our object should be to dissipate it not as quickly but as quietly as possible. A sudden dissipation of energy is always violent. No one in his senses wishes to stop a fly wheel or a railway train suddenly; sudden or hasty dissipation is not what is wanted. Gun cotton possesses a store of potential energy locked up in it to a dangerous extent; if it be dissipated suddenly, as by percussion, a violent explosion results; but if it be dissipated gradually, as by a flame, the energy is got rid of without much damage, beyond the liability to fire. An armor plate may be able to stop a cannon ball quickly, but a heap of sand or loose earth does it more safely, because more gradually.

So it is exactly with the store of energy beneath an electrified cloud or between one cloud and another. A lightning conductor of perfect conductivity, if struck, would deal with the energy in far too rapid and sudden a manner, and the result would be equivalent to an explosion. A conductor of moderately high resistance, such as an iron wire, would get rid of it in a slower and therefore much safer and quieter manner, though with too thin a wire there may be risk of fire.

The rush in any case, however, is likely to be rather violent, and, like an avalanche, it will not take the easiest path provided for it, as if it were a trickling stream, but will crash through obstacles and make its own path, some portions

of it taking paths which would be quite unexpected. Hence, no one path can be said to protect others, and the only way to protect a building with absolute completeness is to inclose it wholly in metal. An invisible cage or framework of iron wires, however, descending vertically down its salient features, with the utilization of any metal in its construction, suffices for all practical purposes, unless the building is a powder magazine.

The effect of *points*, and of rain also, in gradually dissipating a charge, and thereby contributing to safety, has long been understood; but the feature which has not been known is that there are cases where points are wholly inoperative, viz, when the energy is stored between cloud and cloud, instead of between cloud and earth, and when the initial discharge takes place from one cloud to another; then the lower cloud is liable suddenly to overflow to earth through a region in which there was no previous preparation, and where any number of points, or a rain shower, or any other form of gentle leak, would have been quite inoperative. Then can a violent discharge occur to even the sharpest point; and a hot column of air, such as rises up a chimney, is even preferred to a conductor. These are the flashes against which points and rain are no protection, and these are probably those which do the most damage to protected buildings. But it must be understood that when a flash does occur through a building, it matters little which kind of flash it is—both can be equally sudden and violent—but if the building is well provided with points, the first or prepared kind is not likely to occur, save in exceptional cases, the dangerous liability is then the sudden or overflow variety of flash.

These, then, are the two points of novelty:

1. The possible occurrence of a totally unprepared-for and sudden flash in previously unstrained air, by reason of overflow from a discharge initiated elsewhere, what is called the *B* spark, occurring as the secondary result of an *A* spark.

2. The effect of electrical inertia or momentum, so that the discharge is not a simple leak or flow in one direction, but a violent oscillation and splash or impulsive rush, much more like an explosion, and occurring in all directions at once, without much regard to the path which had been provided for it; no more regard, in fact, than is required to enable the greater part of it to take the good conductors, and to prevent any part of it from being able to enter a perfectly inclosed metallic building.

Even a small lateral fraction of a flash is able, however, to ignite gas if there is a leak, or even to *make* a leak at a "compo"-pipe where it is crossed by a bell wire, and then ignite it; hence, after a building has been struck, careful watch should be kept for some time against the danger of fire.

The amount of protection to be allotted to any building is no doubt analogous to the question of insurance generally; that is to say, the amount of premium it is desired to pay may be compared with the capital at stake and the risk run; and this is doubtless a matter for individuals and public bodies to consider for themselves. What the committee can do is to make a study of cases of damage occurring to buildings which on the old lines were supposed to be protected, to tabulate them as below, and to ask for carefully recorded observations; they can also draw up such hints and suggestions as may be of use to architects whose clients desire their buildings to be protected in a more thorough, but not necessarily a more expensive manner.

These objects, and these attempts at being useful, explain the existence of the present report.

OBSERVATIONS AND SUGGESTIONS.

It has been pointed out by Sir Oliver Lodge that lightning discharges are of two distinct characters, which he has named the *A* flash and the *B* flash, respectively.

The *A* flash is of the simple type which arises when an electrically charged cloud approaches the surface of the earth without an intermediate cloud intervening, and under these conditions the ordinary type of lightning conductor acts in two ways: first, by silent discharge; and secondly, by absorbing the energy of a disruptive discharge. In the second type, *B*, where another cloud intervenes between the cloud carrying the primary charge and the earth, the two clouds practically form a condenser; and when a discharge from the first takes place into the second the free charge on the earth side of the lower cloud is suddenly relieved, and the disruptive discharge from the latter to the earth takes such an erratic course *that no series of lightning conductors of the hitherto recognized type suffice to protect the building.*

On the 28th of May, 1904, an interesting demonstration of the action of *A* and *B* flashes, respectively, was given by Sir Oliver Lodge before members of the committee and others interested in these researches. A thin sheet of metal mounted on nonconducting standards represented the cloud, which was charged at will from a Leyden jar. The "cloud" was so arranged that the model lightning conductors could have their points brought nearer to or farther from its under surface by shifting their positions on the table. Conductors of copper, iron, and wet string were experimented with. The disruptive discharge to the copper proved to be by far the loudest and most intense of the three. The iron took the flash with less noise, the wet string, with hardly any; yet when the discharge passed through it the other and apparently better conductors were not affected. The experiments tended to demonstrate that iron is in many situations a very useful material for lightning rods, as the effective energy of a flash of lightning is rapidly dissipated in iron. This metal, however, unfortunately oxidizes rapidly in towns and smoky districts, and the use of copper as a material for a lightning rod is still recommended for main conductors in relatively inaccessible positions, although iron is electrically preferable.

A consideration of the descriptions of recent foreign practice given in Appendix B, and of the cases which appear in the summary of damage, Appendix A, (not here reprinted) justifies the following general observations:

It is probable that with few exceptions buildings in this country are not in reality efficiently protected against the effects of a *B* flash, although in many cases the lightning conductors may be said to have at least partially fulfilled their purpose by carrying off the more violent portion of a discharge, and that without them greater damage would have occurred in many of the cases reported.

Some of these observations throw a very interesting light on the effects due to the oscillatory character of lightning discharges. For instance, a discharge takes place over a lightning rod which may be in contact with, or approach closely to, the metallic portions of a roof. Powerful electrical oscillations are set up in the latter conductors, and dangerously high electrical pressure may be generated on the distant ends of these conductors. If at these points they were connected to earth the pressure would be relieved, and the discharge harmlessly dissipated. Without this safe path the discharge may break away into the down pipes, or may pierce the roof to reach internal conductors. Cases which appear to indicate successive or simultaneous flashes may be due to a single flash setting up these oscillations.

In some cases the damage done to a building by an *A* flash is not necessarily due to the primary discharge. A lateral discharge occasionally occurs which frequently causes minor, though in some cases serious, damage owing to falling materials.

Many of the reports of damage to unprotected buildings show that the lightning discharge followed the path of wire ropes, metallic pipes, and other conductors, and that the damage to the structure occurred at the breaks in continuity at the upper and lower terminals, respectively.

It may be considered that a lightning conductor of the ordinary type, if properly constructed, affords an undefined area of protection against *A* flashes, but it can not be said to have any protective area against *B* flashes.

Absolute protection of the whole of a building could only be assured by inclosing the structure in a system of wirework—a contrivance, in fact, of the nature of a bird cage. This should be well connected at various points to earth, as nearly all buildings have gas and water pipes and other metallic conductors in their interiors which are likewise earthed. For structures intended for the manufacture or storage of gunpowder and other explosives the adoption of this bird cage protection would be justified on the score alone of public safety. Architectural considerations prevent the adoption of such a method in its entirety for ordinary buildings. There is no doubt, however, that practically perfect protection may be assured by a judicious modification of the existing practice of erecting single lightning rods, especially in the case of extensive and lofty buildings that project well above surrounding structures or that stand isolated in the open country.

It is obvious that the extent to which the building should be protected and the expense to be incurred in this protection must bear some definite relation to the importance or cost of the building itself. In cases where protection is considered desirable, but heavy expense is not justified, two or more lightning rods might be erected in the ordinary manner, these being connected by a horizontal conductor, and the metal portions of the roof and the rain water down pipes should be metallically connected and well earthed.

Tall chimney shafts are not efficiently protected against a *B* flash by an ordinary single lightning rod, as a hot column of smoke issuing from a chimney conducts as well or even better than a rod. A circular band should surround the top of the shaft; four or more conductors should be raised above the latter in the form of a coronal, or the continental practice of joining the elevation rods together, so as to form an arch over the chimney, may be employed with advantage. One or, preferably, two lightning rods should extend from this circular band to the earth in the manner described below.

As most buildings contain systems of gas and water pipes, a good earth for the lightning conductors is highly desirable. In the case of a stove inside a building with a metallic stovepipe carried outside the stove should be earthed and a wire be led from the pipe to earth outside, or to the nearest conductor.

The various cases noted by the committee show that while even single conductors tend to diminish the damage done to buildings by lightning no reliance can be placed on an area of protection. Judging by the latest foreign practice, continental experience appears to be confirmatory of this view (see Holland, Hungary, and Germany, Appendix B). In churches and other buildings with spires and towers the lower projections should also be protected, even if forming part of the salient features of the building.

No cases of damage to modern steel frame structures have come under the notice of the committee. The ordinary method of construction, however, in this country does not provide full protection. In many cases the steel columns stand on stone foundations and the metal is not carried deep enough for effective earthing. The metal columns ought to be earthed at the time of construction.

In the opinion of the committee, the methods advocated in the Report of the Lightning Rod Conference still hold good, provided arrangements are made to keep the earth permanently moist. The committee therefore deems it convenient to print here the rules issued by the Lightning Rod Conference in 1882, supplementing them with observations and suggestions of their own based on the results of their recent researches.

RULES FOR THE ERECTION OF LIGHTNING CONDUCTORS, AS ISSUED BY THE LIGHTNING ROD CONFERENCE IN 1882, WITH OBSERVATIONS THEREON BY THE LIGHTNING RESEARCH COMMITTEE, 1905.

[NOTE. – Paragraphs beginning with odd numbers refer to Lightning Rod Rules, 1882; those with even numbers to Lightning Research Committee's observations, 1905.]

1. POINTS.—The point of the upper terminal should not be sharp, not sharper than a cone of which the height is equal to the radius of its base. But a foot lower down a copper ring should be screwed and soldered on to the upper terminal, in which ring should be fixed three or four sharp copper points, each about 6 inches long. It is desirable that these points be so platinized, gilded, or nickel plated as to resist oxidation.

2. It is not necessary to incur the expense of platinizing, gilding, or electroplating. It is desirable to have three or more points beside the upper terminal, which can also be pointed; these points must not be attached by screwing alone, and the rod should be solid and not tubular.

3. UPPER TERMINALS.—The number of conductors or points to be specified will depend upon the size of the building, the material of which it is constructed, and the comparative height of the several parts. No general rule can be given for this, but the architect must be guided by the directions given. He must, however, bear in mind that even ordinary chimney stacks, when exposed, should be protected by short terminals connected to the nearest rod, inasmuch as accidents often occur owing to the good conducting power of the heated air and soot in the chimney.

4. This is dealt with below in suggestion 3 (page 16).

5. INSULATORS.—The rod is not to be kept from the building by glass or other insulators, but attached to it by metal fastenings.

6. This regulation stands.

7. FIXING.—Rods should preferentially be taken down the side of the building which is most exposed to rain. They should be held firmly, but the holdfast should not be driven in so tightly as to pinch the rod or prevent the contraction and expansion produced by changes of temperature.

8. In most cases it would be advantageous to support the rods by holdfasts (which should be of the same metal as the conductor) in such a manner as to avoid all sharp angles. The vertical rods should be carried a certain distance away from the wall to prevent dirt accumulating and also to do away with the necessity of their being run round projecting masonry or brickwork.

9. FACTORY CHIMNEYS.—These should have a copper band around the top, and stout, sharp copper points, each about one foot long, at intervals of two or three feet throughout the circumference, and the rod should be connected with all bands and metallic masses in or near the chimney. Oxidation of the points must be carefully guarded against.

10. As an alternative, the rods above the band might with advantage be curved into an arch provided with three or four points. It is preferable that there should be two lightning rods from the band carried down to earth in the manner previously descrided. Oxidation of the points does not matter.

11. ORNAMENTAL IRONWORK.—All vanes, finials, ridge ironwork, etc., should be connected with the conductor, and it is not absolutely necessary to use any other point than that afforded by such ornamental ironwork, provided the connection be perfect and the mass of ironwork considerable. As, however, there is a risk of derangement through repairs, it is safer to have an independent upper terminal.

12. Such ironwork should be connected as indicated below in suggestion 3. In the case of a long line of metal ridging a single main vertical rod is not sufficient, but each end of the ridging should be directly connected to earth by a rod. Where the ridge is nonmetallic a horizontal conductor (which need not be of large sectional area) should be run at a short distance above the ridge and be similarly connected to earth.

13. Material for rod.—Copper, weighing not less than 6 ounces per foot run, and the conductivity of which is not less than 90 per cent of that of pure copper, either in the form of tape or rope of stout wires—no individual wire being less than No. 12 B. W. G. Iron may be used, but should not weigh less than 2¼ pound per foot run.

14. The dimensions given still hold good for main conductors. Subsidiary conductors for connecting metal ridging, etc., to earth may with advantage be of iron and of a smaller gage, such as No. 4 S. W. G. galvanized iron. The conductivity of the copper used is absolutely unimportant, except that high conductivity increases the surges and side flashes, and, therefore, is positively objectionable. It is for that reason that iron is so much better.

15. Joints.—Although electricity of high tension will jump across bad joints, they diminish the efficacy of the conductor; therefore every joint, besides being well cleaned, screwed, scarfed, or riveted, should be thoroughly soldered.

16. Joints should be held together mechanically as well as connected electrically, and should be protected from the action of the air, especially in cities.

17. Protection.—Copper rods to the height of 10 feet above the ground should be protected from injury and theft by being inclosed in an iron pipe reaching some distance into the ground.

18. This regulation stands.

19. Painting.—Iron rods, whether galvanized or not, should be painted; copper ones may be painted or not according to architectural requirements.

20. This regulation stands.

21. Curvature.—The rod should not be bent abruptly round sharp corners. In no case should the length of the rod between two points be more than half as long again as the straight line joining them. Where a string course or other projecting stonework will admit of it, the rod may be carried straight through, instead of round the projection. In such a case the hole should be large enough to allow the conductor to pass freely, and allow for expansion, etc.

22. The straighter the run the better. Although in some cases it may be necessary to take the rod through the projection, it is better to run outside, keeping it away from the structure by means of holdfasts, as described above.

23. Extensive masses of metal.—As far as practicable it is desired that the conductor be connected to extensive masses of metal, such as hot-water pipes, etc., both internal and external; but it should be kept away from all soft metal pipes, and from internal gas pipes of every kind. Church bells inside well-protected spires need not be connected.

24. It is advisable to connect church bells and turret clocks with the conductors.

25. Earth connections.—It is essential that the lower extremity of the conductor be buried in permanently damp soil; hence proximity to rain-water pipes, and to drains, is desirable. It is a very good plan to make the conductor bifurcate close below the surface of the ground, and adopt two of the following methods for securing the escape of the lightning into the earth. A strip of copper tape may be led from the bottom of the rod to the nearest gas or water *main*—not merely to a lead pipe—and be soldered to it; or a tape may be soldered to a sheet of copper 3 feet by 3 feet and $\frac{1}{16}$-inch thick, buried in permanently wet earth, and surrounded by cinders or coke; or many yards of the tape may be laid in a trench filled with coke, taking care that the surfaces of copper are, as in the previous cases, not less than 18 square feet. Where iron is used for the rod, a galvanized-iron plate of similar dimensions should be employed.

26. The use of cinders or coke appears to be questionable owing to the chemical or electrolytic effect on copper or iron. Charcoal or pulverized carbon (such as ends of arc-light rods) is better. A tubular earth consisting of a perforated steel spike driven tightly into moist ground and lengthened up to the surface, the conductor reaching to the bottom and being packed with granulated charcoal, gives as much effective area as a plate of larger surface, and can easily be kept moist by connecting it to the nearest rain-water pipe. The resistance of a tubular earth on this plan should be very low and practically constant.

27. Inspection.—Before giving his final certificate the architect should have the conductor satisfactorily examined and tested by a qualified person, as injury to it often occurs up to the latest period of the works from accidental causes, and often from carelessness of workmen.

28. Inspection may be considered under two heads:

A. The conductor itself.

B. The earth connection.

A. Joints in a series of conductors should be as few as possible. As a rule they should only be necessary where the vertical and horizontal conductors are connected, and the main conductors themselves should always be continuous and without artificial joints. Connections between the vertical and horizontal conductors should always be in places readily accessible for inspection. Visible continuity suffices for the remainder of the circuit. The electrical testing of the whole circuit is difficult, and needless.

B. The electrical testing of the earth can in simple cases be readily effected. In complex cases, where conductors are very numerous, tests can be effected by the provision of test clamps of a suitable design.

29. Collieries.—Undoubted evidence exists of the explosion of fire-damp in collieries through sparks from atmospheric electricity being led into the mine by the wire ropes of the shaft and the iron rails of the galleries. Hence the head gear of all shafts should be protected by proper lightning conductors.

SUGGESTIONS OF THE COMMITTEE.

The investigations of the committee warrant them in putting forward the following practical suggestions:

1. Two main lightning rods, one on each side, should be provided, extending from the top of each tower, spire, or high chimney stack by the most direct course to earth.

2. Horizontal conductors should connect all the vertical rods (*a*) along the ridge, or any other suitable position on the roof; (*b*) at or near the ground.

3. The upper horizontal conductor should be fitted with aigrettes or points at intervals of 20 or 30 feet.

4. Short vertical rods should be erected along minor pinnacles and connected with the upper horizontal conductor.

5. All roof metals, such as finials, ridging, rain water, and ventilating pipes, metal cowls, lead flashing, gutters, etc., should be connected to the horizontal conductors.

6. All large masses of metal in the building should be connected to earth either directly or by means of the lower horizontal conductor.

7. Where roofs are partially or wholly metal lined they should be connected to earth by means of vertical rods at several points.

8. Gas pipes should be kept as far away as possible from the positions occupied by lightning conductors, and as an additional protection the service mains to the gas meter should be metallically connected with house services leading from the meter.

(Signed)

John Slater, *Chairman,*
E. Robert Festing,
Oliver Lodge,
J. Gavey,
W. N. Shaw,
A. R. Stenning,
Arthur Vernon,
Killingworth Hedges,
Honorary Secretary,
G. Northover, *Secretary.*

APPENDIX B.

LATEST PRACTICE ABROAD.

Holland.

The following is translated from the Dutch of the very complete and valuable report made by Dr. D. van Gulik at the request of the Dutch Academy of Science, which has just been published under the title of Further Inquiries in Regard to the Protection of Buildings from Lightning (Haarlem, 1905):

1. Lightning conductors serve to lessen the risk of fire and of serious damage for the buildings protected by them, and to reduce considerably the danger to life for those who inhabit the buildings. Whether the risk of a building being struck by lightning is also lessened by the installation of points or bundles of points is very doubtful. Where, therefore, economy is an object these may be first dispensed with.

2. In protecting buildings from lightning we must bear in mind that, contrary to what we notice in the case of constant electric currents—

(*a*) Lightning shows a great tendency to distribute itself over such conductors as may be present, and in so doing to pay little heed to the electrical resistance of the conductor.

(*b*) That it finds no great diffiulty in making its way, often for a considerable distance, through the air or through any other good conducting medium.

(*c*) That it prefers to move, as far as possible, in a straight line, and that, therefore, sharp turns or spiral windings in conductors present hindrances which, in view of the properties mentioned in paragraphs *a* and *b*, readily lead to lateral discharges.

Absolute security is not attainable or attainable only with great difficulty, and in any case at considerable expense. On the other hand a quite satisfactory degree of protection can be secured by very simple means.

3. The greater the importance attached to the preservation of a building and its contents the more perfect can the system of conductors be made, and thus a higher coefficient of safety is obtained by increased expenditure.

4. The conductors at present used in Holland secure a fairly high degree of safety in the case of houses with tiled or slated roofs, as they reduce the risk of fire when struck to an average of between one-sixth or one-seventh. Statistics show, however, that the lightning frequently diverges from them and may even strike the buildings without touching the terminal rods. Moreover, the cost of installation is so great that many people are deterred thereby from having these useful appliances fitted. Certain general improvements and simplifications may, however, be pointed out, by means of which the conductors would, even at a lower cost, better answer the purpose for which they are intended.

5. The *improvements* are in the main as follows:

(*a*) All salient positions liable to be struck should be provided with terminals in the form of short rods or wires, and the roof should be girt round on all sides by wire conductors. This would take the place of the high terminal rods with their imaginary cone of safety.

(*b*) Several conductors running to the earth should be fitted.

(*c*) The system of conductors should be connected with any extensive metallic mass present in the building, if necessary at more points than one. In the case of gas and water pipes such connection is absolutely necessary.

6. The principal *simplifications* may be summed up thus:

(*a*) High terminal rods should be abolished, as it is difficult to fix them firmly enough.

(*b*) Copper, which is the material generally used for conductors and earth connections, should be replaced by iron. This, if well galvanized, will resist atmospheric influences for a very long time and can, moreover, be easily protected by a coat of paint.

(*c*) The thickness of the conductors should be reduced. In support of this we may adduce the evidence of the ordinary telegraph wire, which is seldom, if ever, found to be melted, except at the point where it is struck. Even in providing for extreme cases we should not lose sight of the fact that a wire will do its duty even though it succumbs to the force of the stroke.

(*d*) The metallic constructional portions of the building should be pressed into service as conductors. By this means either the conducting system is extended, with a consequent increase in the margin of safety, or the use of special conductors may be partly dispensed with. This last expedient proves a ready means, in the case of special classes of buildings, of providing quite efficient conductors at a trifling cost. It is not necessary that there should be metallic contact between the metal constructions provided that they overlap one another over an area of 10 square centimeters.

7. In making earth connections too much importance is often attached to reaching the ground water level, while on the other hand too little care is taken to secure a good connection between the conductor and the uppermost layer of soil. By paying attention to this a considerable saving may in some cases be made in the cost of earth contact. In isolated cases where connection with underground pipes, etc., is possible, no special earth connection is necessary.

8. When building houses it is desirable that the conductors should always be marked on the plans. This makes their installation easier and reduces the cost. Moreover, it enables architects to exclude from their plans constructions which would tend to increase the risk of fire in the event of the house being struck by lightning.

9. Special precautions are necessary in the case of thatched roofs. These consist mainly in keeping the conductors some distant away from the roof and in making the wire of such thickness that it shall not be destroyed at the point where it is struck by lightning. If this be done, a high degree of safety is attainable even in the case of thatched roofs.

Hungary.

Through the good offices of the Rector of the Royal Joseph Polytechnical University, Budapest, Dr. Moritz von Hoór kindly favored the committee with the following remarks concerning the precautions against lightning now coming into use in Hungary, showing the method of their installation and their efficacy as proved by experience:

Up to the year 1892, in Hungary as well as in other countries, lightning conductors with collecting points according to the Franklin system were the only ones in use. Here, as elsewhere, the view was universally accepted that absolute security for the efficiency of lightning conductors was afforded by the largest possible cross section of the lightning rod, by a slight change of the collecting apparatus, and by a good earth connection. It was held, therefore, that a conductor had been rightly set up when the collecting point and the earth had been connected by strong copper wires or cables, and care had been taken for a good earth contact.

Experience of such lightning conductors, however, as well as observations systematically taken in England and the English colonies, and in Germany, proved that lightning rods on this principle did not answer their purpose, and in particular that the directions as to the area of protection of the conductor and the relation between height and base of the protected zone were of no practical value and quite baseless.

It was repeatedly observed that there were lateral discharges from the conductor in the direction of the metal parts (badly connected apparently with the earth), that sparks leaped over curves in the conduction apparatus, and in general that buildings and other objects protected by the collecting points suffered damage from lightning, though to a far less extent, as shown by statistics, than objects altogether unprovided with lightning conductors.

Prof. Moritz von Hoór, following up the work of Hertz and Lodge, was the first in our country to treat this question theoretically and experimentally in a scientific manner on the basis of the new principles, and he was the first here to suggest the abandonment of the conductors with collecting points, and the introduction of contour conductors without collecting points similar to Faraday's parrot cage.

Leopold Stark, chief engineer of Messrs. Ganz & Co., has since made an exhaustive study of this question, and has worked out various practical plans for cage conductors, with a special view to their application to the protection of agricultural objects peculiarly exposed to risks from lightning (cf. *Villámhárítók különös tekintettel mezögazdasági epületekre*, irta: Stark Lipót gépészmérnok, Budapest, Fövárosi Nyomda, 19 3).

For some years now, as a result of these works and of the agitation started by the above-mentioned scientists, cage lightning conductors of this kind have been largely in use with us, both on town buildings and on agricultural objects. They consist, as Sir Oliver Lodge, and, long before him, Faraday, suggested, of barbed wire, or strong iron wire, or sheet iron bands, which, following the contours of the roof and building or other objects conduct to separate earth connections or to connections joined underground by a circular conducting wire.

The cost of such conductors is with us hardly more than that of the conductors with gilt collecting points and copper conducting wires, and they have been found admirably efficacious as might have been deduced from theoretical reasoning, so that the military authorities both in Austria and Hungary have had all magazines of explosives protected in this manner.

Special care is taken, in setting up these cage conductors, to avoid the sharp curves arising from a sudden change in the direction of the earth conductors, so as to reduce as far as possible the self-induction of the earth connection.

Importance is also attached to good earths, but experience shows that if the cage arrangement is well carried out and the number of cage wires not too scanty, even without a very good earth connection, the conductor still works satisfactorily.

At present both the cage and the Franklin collecting point systems are in use with us; but of late years, especially for agricultural objects, the cage system is coming more and more in vogue, and probably in a short time all the new conductors will be of this kind.

Germany.

The following is extracted from the Regulations of the Electro-Technical Society of Berlin, issued in 1901:

1. The lightning receivers should consist of vertical points. The points of towers or gables, edges of the ridge of the roof, tops of chimney stacks, and other high parts of buildings should be converted into receivers or be provided with suitable receivers. The conductors should be in metallic connection with the receivers and the earth; they should go round the building, especially in the roof, and if possible on all sides, and then be led from the receivers to the ground by the most direct route, avoiding as much as possible all sharp curves. The earth connections should consist of metallic conductors connected to the lower conductors on the building, and should descend into the ground and extend as far as possible, preferably where the earth is damp.

2. The metallic parts of the building and masses of metal in and upon it, especially those in contact with the earth and offering large surfaces (such as pipes),

should be connected together as much as possible, and to the conductor also. Special receivers and conductors are rendered unnecessary if these metallic parts of the building comply with the requirements mentioned in paragraphs 1, 4, and 5. Both for perfecting the system and for decreasing cost, the question of utilizing the pipes as conductors should be considered when erecting new buildings, making use also as much as possible of all the metallic parts of the building for protective purposes.

3. The protection afforded by a conductor is the greater the more perfectly all the prominent portions of the building are protected by receivers, the larger the number of receivers and conductors, and the more extended the connections to earth. Generally speaking, damage by lightning is diminished if all the metallic parts of buildings of considerable extent are interconnected, especially if the highest parts are connected to earth, even if these connections are not made specially with a view to protection from lightning.

4. Interconnected conductors of iron should not have a section of less than 50 square millimeters, unconnected ones not less than 100 square millimeters. If of copper, half the section is sufficient; zinc must be one and a half, and lead three times the section for iron. Conductors must be securely fixed to resist strong winds.

5. The connections of and to the conductors must be made strong, be of good electrical contact, and with as large a surface as possible. Unwelded and unsoldered connections should have metallic surfaces of contact of not less than 10 square centimeters.

The lightning-conductor system should be repeatedly tested; and when alterations are made in the building, the necessity of alterations in the lightning-conductor system should be considered.

Baurat Findeisen, of Stuttgart, deduces from certain statistics as to strokes by lightning in Würtemberg that there is some doubt as to the efficacy of intercepting rods in attracting and protecting against lightning, and that there is no point in measuring the resistance of lightning conductors, since the high pressure of lightning would overcome even high degrees of resistance. It would be sufficient, he thinks, if all the protecting sheet metal on the roof ridge and elsewhere were connected with the gutters and rain-water pipes—if the chimney, which is so often struck, were protected by a rope (3 to 4 mm.) of galvanized iron wire, projecting to a height of one-half to one meter above the chimney, and joined as a conductor with the protecting metal, and if the water pipes were used as earth connections, they also having a strong wire rope running along them, which, at the lower end should be untwisted and carried in fan shape about half a meter down into the ground. Four such earth connections at the corners of the building to be protected would suffice. If yet further precautions are desired, galvanized sheet iron might be substituted for this. Lightning conductors of this type have proved their efficiency.